Globally Polarized Quark-gluon Plasma in Non-central $A + A$ Collisions [1]

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Strong transverse polarization of hyperons has been observed in unpolarized $p + p$ and $p + A$ collisions since the 1970's. Given the beam and hyperon momenta $\vec{p}$ and $\vec{p}_H$, hyperons produced in the beam fragmentation region are found transversely polarized in the direction perpendicular to the hyperon production plane, $\vec{n}_H = \vec{p} \times \vec{p}_H / |\vec{p} \times \vec{p}_H|$. Polarizations of Λ, Ξ and $\bar{\Xi}$ are negative while Σ and $\bar{\Sigma}$'s are positive. In the meantime, $\bar{\Lambda}$ and Ω are not transversely polarized. Although the origin for such striking transverse hyperon polarization is still in debate, one can relate it to the single-spin left-right asymmetries observed in hadron-hadron collisions with transversely polarized beam, which in turn can be attributed to the orbital angular momenta (o.a.m.) of the valence quarks in a polarized nucleon, or fragmentation functions of transverse polarized quarks as well as twist-3 parton correlations in nucleons. It has also been suggested that hyperon polarization could disappear due to the formation of QGP.

In this Letter [1], we show that parton interaction in *non-central* heavy-ion collisions leads to a global quark polarization along the opposite direction of the reaction plane,

$$\vec{n}_b = \vec{p} \times \vec{b} / |\vec{p} \times \vec{b}|, \tag{1}$$

as determined by the nuclear impact parameter $\vec{b}$. This global polarization is essentially a local manifestation of the global angular momentum of the colliding system through interaction of spin-orbital coupling in QCD. It will have far reaching consequences in non-central heavy-ion collisions, such as left-right asymmetry of hadron spectra in the reaction plane, global transverse polarization of direct photons, dileptons and hadrons with spin. Within different hadronization scenarios, we will discuss hyperon polarization as a result of the global quark polarization. Possible contribution from final state hadronic interaction will also be discussed.

We consider two colliding nuclei with the beam projectile moving in the direction of the z axis, as illustrated in Fig. 1. We define the impact parameter $\vec{b}$ (along $\hat{x}$) as the transverse distance of the projectile from the target nucleus and the reaction plane as given by $\vec{n}_b$ (along $\hat{y}$) in Eq. (1). Partons produced in the overlapped region of the collision will carry a global angular momentum along the direction opposite to the reaction plane ($-\hat{y}$). A thermalized QGP requires final state parton interaction. Given the nature of partonic interaction at high energy, the global angular momentum would never lead to a collective rotation of the system. It will, however, be manifested in the finite transverse (along $\hat{x}$) gradient of the average longitudinal momentum $p_z(x, y, b)$ per produced parton. We assume for the moment that $p_z(x, y, b)$ is independent of the longitudinal position and is just an average value. Given the range of interaction Δx, two colliding partons will have relative longitudinal momentum $\Delta p_z = \Delta x dp_z/dx$ with o.a.m. $L_y \sim -\Delta x \Delta p_z$ along the direction of $\vec{n}_b$. This relative o.a.m. L_y will lead to global quark polarization due to spin-orbital coupling.

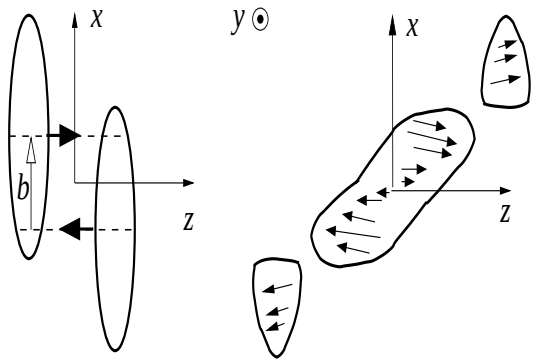

FIG. 1: The geometry of non-central heavy-ion collisions .

The produced partons are shown to have large local relative o.a.m. in non-central heavy-ion collisions if quark-gluon plasma is formed. Parton scattering with given relative o.a.m. is shown to polarize quarks along the same direction due to spin-orbital coupling, with global quark polarization,

$$P_q = -\pi\mu \; p/4E(E + m_q) \tag{2}$$

via a single scattering for given E. Such global quark polarization has many measurable consequences in high-energy heavy-ion collisions. Within different hadronization scenarios, we predict that hyperons will be polarized along the opposite direction of the reaction plane. Effects of hadronic interaction are expected to be small and would not change the qualitative feature of our prediction.

[1] Z.-T. Liang and X.-N. Wang, Phys. Rev. Lett. **94**, 102301 (2005), nucl-th/0410079.